# FINAL REPORT

Title: Predicting fire-mediated forest structure over biophysical gradients in moist mixed-conifer forests

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## KEYWORDS

Fire history, Dendroecology, Fire regime, Fire severity, Mixed-severity fire regime, Moist mixed-conifer forest, Post-fire tree establishment

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This work wouldn't have been possible without help from our dedicated field and lab assistants. Thank you, Katya Davidson, Jennifer Litteral, Josefa Ovalle, Joseph Riggs, Desiree Monarrez, Sebastian Singleton, Maddie Collins, Alex Fager, Jeff Smith, Sebastian Busby, Anthony Holmes, Kayla Johnston, Ian Mott, and Devin Wilde for the countless hours that you've dedicated to help collect and process these tree ring samples.

# ABSTRACT

High variability in historical fire patterns characteristic to mixed-severity fire regimes is expected to have contributed to a structurally and compositionally heterogeneous landscape throughout much of the forested ecosystems of the western United States. After more than a hundred years of fire exclusion in the region, many forests have shifted to a more homogeneous and contiguous structure and composition, which raises concern regarding these forests' ability to withstand expected stressor increases due to climate change, including fire. The structural shift is not uniform across the west, however, and differences in historical disturbance patterns and changes due to land management are not well characterized in some forests or environmental (i.e. bioclimatic) settings. While there is broad agreement on the high impact of fire exclusion on the structure and composition of low elevation, dry forests in the west, much less is known about its effect in mid elevation, moist mixed-conifer forests.

In order to provide reference conditions of wildfire patterns and regeneration dynamics, this study reconstructs the variability in historical fire occurrence and severity and tree establishment in moist mixed-conifer forests in northeastern Oregon's Blue Mountains. We used a novel multi-proxy approach, combining historical aerial photos, dendroecology, and mathematical models to comprehensively sample and reconstruct multi-century fire frequency and severity, and forest structural and compositional patterns. We quantified historical fire severity and assessed the spatial heterogeneity of disturbance and tree establishment patterns from over 1000 tree-core and 160 fire-scar samples collected at 67 plots across 15,600 ha in two study sites. To determine the role of climate variability on forest dynamics, we evaluated synchrony of fire activity and tree establishment at the forest type and subwatershed scale. We identified high spatiotemporal variability in historical fire patterns over fine scales between forest stands. Despite speculation that moist mixed-conifer forests experienced primarily infrequent and severe fires, our results show that fires were relatively frequent (i.e. median intervals ranging from 14-42 years, and 21-84 in the two sites) prior to the early 1900s, with high spatial variability of fire severity that created a fine-scale patchwork of stand ages and successional characteristics across the study area. Concurrent post-fire establishment pulses of both shade-intolerant and shade-tolerant species were common in both sites. Fires declined abruptly after the early 1900s. Overall the results of this study highlight the complexity of the mixed-severity fire regime in these forests, contribute to our understanding of post-fire regeneration dynamics of shade-tolerant species, shed light on the effects of past fire suppression activities, and will help inform discussions around appropriate restoration activities in moist mixed-conifer forests of the northern Blue Mountains Ecoregion.

# 1. PROJECT OBJECTIVES

1) *To better understand the myriad of effects of the mixed-severity fire regime on moist mixed-conifer forests across a topographically and biophysically heterogeneous landscape.*

**Completed for both sites.** The graduate student investigator used funding from the Joint Fire Science Program's Graduate Research Innovation Award to support the processing of over 400 tree core and 65 fire scar samples in the lab. These samples were combined with another tree ring dataset collected and processed by the graduate student at another site the previous summer, which when combined allowed for a suite of analyses using over 1000 tree core and 160 fire scar samples. The results from the first sampled site (Jubilee Lake) are presented in the graduate student's master's thesis, while analyses from both sampled sites will be presented in the manuscript in preparation.

2) *Provide mechanistic insights into how variations in fire frequency and severity structure forest recovery and shape successional trajectories, and how these dynamics vary across steep biophysical gradients.*

**Completed for both sites.** Similar to the descriptions in *Objective 1*, we completed this objective with the newly acquired dendroecological datasets. The results from the first sampled site (Jubilee Lake) are presented in the graduate student's master's thesis, while ongoing analyses from both sampled sites will be presented in the manuscript in preparation.

# 2. BACKGROUND

Over recent decades in the western United States, there has been an increase in the frequency of large wildfires associated with longer fire seasons (Westerling 2006). This trend, at least in part, is attributable to anthropogenic climate change that continues to lead to increased fuel aridity (Abatzoglou and Williams 2016) and earlier spring snowmelt (Westerling 2006). There is concern that today's forests, many of which have experienced substantial structural and compositional changes over the past century due to Euro-American land use (e.g. grazing, logging, burning, and/or fire suppression; Hessburg et al. 2000), will not be resilient to the anticipated trend in wildfire patterns (Davis et al. 2018; Coop et al. 2020; Bowman et al. 2020). However, local context is important, and it is not fully understood whether and to what degree the effects of past and ongoing climate and land use changes are uniform across forest ecosystems in the west (e.g. Haugo et al. 2019). Forests that historically experienced mixed-severity fire regimes are thought to have been widespread in the northwestern US (LANDFIRE 2010; Perry et al. 2011), but due to the challenges associated with studying and classifying past (i.e. historical) fire patterns and dynamics in these forests (Tepley and Veblen 2015; Naficy 2016; Daniels et al. 2017) they remain the least understood (Schoennagel et al. 2004). In particular, moist mixed-conifer (MMC) forests, some of which are expected to have experienced mixed-severity fire regimes, are understudied in comparison to the relatively lower elevation, dry pine forests and the higher elevation wet forests (Stine et al. 2014). Thus, a baseline understanding of fire regimes and ecological dynamics is needed in these forests, and can inform our understanding of the consequences of past and future stand structural changes under current and projected climate and management scenarios (Hessburg et al. 2016). This information will aid managers in making informed decisions regarding if and where restoration is appropriate.

Furthermore, the diverse tree species assemblages that characterize mixed-severity fire regime forests often include a mix of fire-resistant and fire-sensitive species, with differing life history traits (e.g. decay resistance; bark thickness), which leads to variability in the preservation of historical fire evidence. This high species diversity also creates complex successional pathways that depend on multiple factors such as pre-fire vegetation, prior disturbance history (e.g. Coppoletta et al. 2016; Busby et al. 2020), the severity and size of burn patches (Tepley et al. 2013 & 2014; Parks et al. 2016) and the site-level microclimatic conditions (Tepley and Veblen 2015; Enright et al. 2015). Though often overlooked (e.g. Agee 1993; Johnson et al. 2001; Franklin et al. 2002), a more nuanced successional framework is an important component in understanding the disturbance dynamics in mixed-severity fire regime forests (e.g. Tepley et al. 2013; Spies et al. 2018).

To overcome the many challenges with reconstructing historical, pre-fire suppression fire patterns in mixed-severity fire regime forests, previous studies have implemented a multi-proxy approach, combining dendroecological data (i.e. tree ring fire scars and post-fire establishment) with forest structure interpretations from historical aerial photographs (Naficy et al. 2015; Naficy 2016). The forest stands (i.e. patches) delineated from the historical aerial photos can have high spatial extent and resolution and are direct observations of spatial patterns of forest structure created by the interaction of previous disturbances with biophysical conditions (Hessburg et al. 1999). One of the many attributes assigned to each patch is a structural classification based on stand development processes (O'Hara et al. 1996). Stand structure is a useful surrogate for historical fire severity because the diversity of tree sizes, stand density, and canopy cover are directly influenced by the history of past fires. (O'Hara et al. 1996; Tepley and Veblen 2015; Naficy 2016). Dendroecological data are often collected over a limited spatial extent, but have very high temporal resolution and extent, and they are the only direct proxy of historical fire occurrence and effects. In mixed-severity fire regime forest patches spatiotemporal fire severity-mediated dynamics are best evaluated using a multi-method research design (Naficy 2016). Here, we combined historical aerial photos with dendroecological data and a structure-based fire severity model to better understand historical disturbance patterns at a landscape scale within the northern Blue Mountains (e.g. Hessburg et al. 2007).

Fire exclusion-mediated changes in forest structure and composition in the western US are well-documented in dry ponderosa pine forests that historically experienced frequent, low severity fire (e.g. Swetnam and Baisan 1996; Hessburg et al. 2005). This homogeneity may expose forests to an array of problems, including increased susceptibility to insect infestation and drought (Pile et al. 2019), and/ or higher fire severity than historically due to increased fuel loading and continuity (Haugo et al. 2019; Cassel et al. 2019). However, there are far fewer studies documenting fire exclusion effects in MMC forests in the Northwest US that historically experienced mixed severity fire regimes (Stine et al. 2014).This has led to debate regarding the extent to which fire exclusion has caused departures from the natural range of variability in these forested ecosystems, how forest change may impact current or future forest resilience, and what type of restoration is appropriate (Odion et al. 2014; Hanson et al. 2015; Hessburg et al. 2016, 2019; Hagmann et al. 2018). More broadly, the frequency and severity of fires and postfire tree regeneration dynamics among dominant species prior to fire suppression era are poorly understood in MMC, and incipient studies suggest that extrapolations from dry or subalpine forests may lead to misleading conclusions (e.g. Tepley et al. 2013; Tepley and Veblen 2015).

The main objective of this work is to provide mechanistic insights into how the historical fire regime (fire frequency and severity) structure forest recovery and successional trajectories, and how these dynamics varied across steep biophysical gradients. We addressed this objective with these specific research questions:

RQ1: What were the effects of fire frequency and severity on forest structure prior to fire suppression?

RQ2: How do fire frequency and severity and stand structure vary with site conditions across biophysical gradients?

To accomplish this, we paired dendroecological sampling with pre-fire suppression aerial photo interpretation to elucidate the disturbance mechanisms that drive historical forest structure at the subwatershed scale. Our results are immediately relevant for upcoming forest management planning and will be made available to local land managers in the BME.

# 3. METHODS

## 3.1 STUDY AREA AND SITE SELECTION

This study was conducted in the Blue Mountains Ecoregion (BME) of northeastern Oregon, United States (**Figure 1**). The BME is the largest ecoregion in Oregon, encompassing roughly 24,000 square miles of geologically diverse and dissected topography that extends into the neighboring states of Idaho and Washington. The Blue Mountains, the largest mountain range within the ecoregion, are characterized by plateaus and isolated uplifted mountain peaks dissected by steep river canyons, and a north-south climatic gradient. The northern portion of the range experiences more precipitation than the southern portion due to its proximity to the Columbia River, which channels moisture from the Pacific Ocean (Mock 1996).

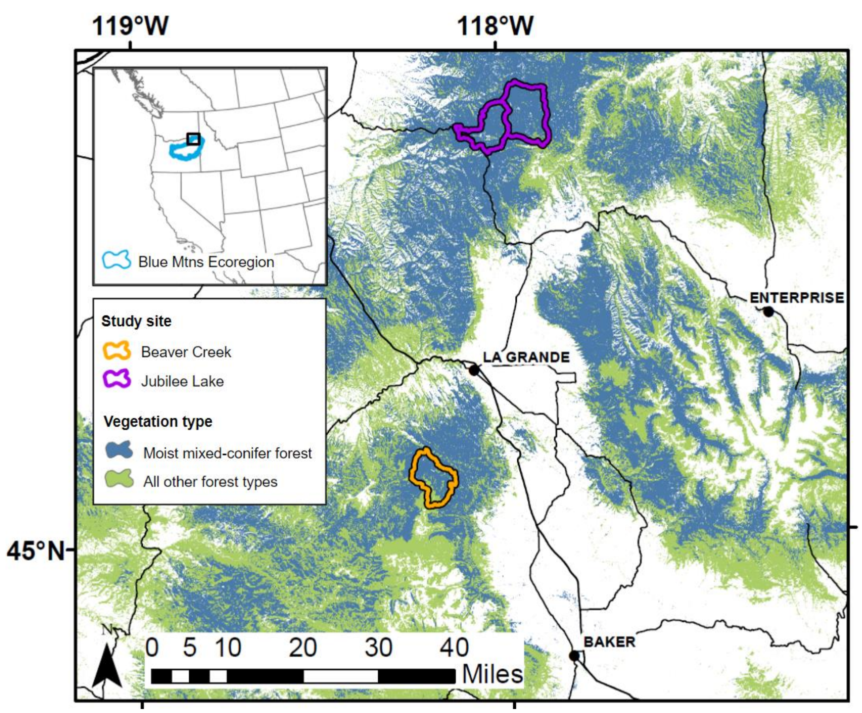



**Figure 1.** Location of two sites within the study area (Jubilee Lake and Beaver Creek) and the three sampled subwatersheds, Upper Lookingglass Creek (left upper), Little Lookingglass Creek (right upper; both in the Jubilee Lake site), and Beaver Creek (lower; in the Beaver Creek site) within the Blue Mountains ecoregion of northeastern Oregon, USA

The study area encompasses = two subwatersheds in the MMC forests in the northern portion of the Blue Mountain range. The northern site is within the Upper and Little Lookingglass Creek subwatersheds (collectively called the Jubilee Lake site), and the southern site is located in the Beaver Creek subwatershed (**Figures 1 & 2**). These subwatersheds encompass approximately 22,200 ha total of mountainous terrain between 1,166 to 1,755 m elevation (**Figure 3**).

Plots were sampled within a mix of potential vegetation classifications (Powell et al. 2007) from 'Cool Wet Upland Forest' (**Figure 2C**), to 'Warm Dry Upland Forest' (**Figure 2D**), with a majority of our sites within the 'Cool Moist Upland Forest' classification (**Figure 2B**). The dissected topography supports a forest mosaic that includes a mix of grand fir (Abies grandis Dougl. ex D. Don Lindl.), western larch (Larix occidentalis Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), and a minor component of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson), and lodgepole pine (*Pinus contorta* Douglas ex Loudon). Lodgepole pine formed a substantial overstory component at Beaver Creek whereas Jubilee Lake was dominated more by grand fir.

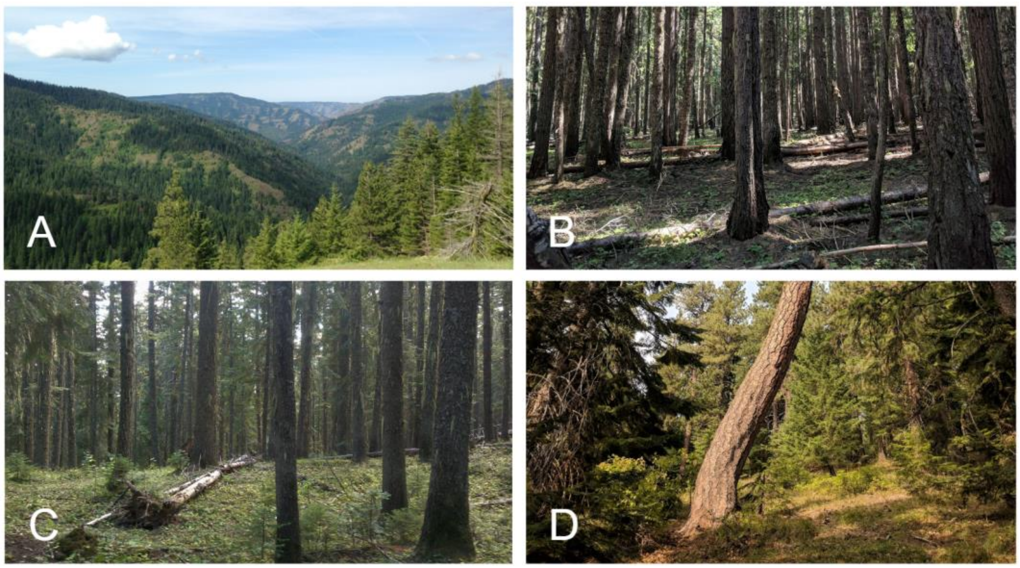



**Figure 2.** Photos depicting **(A)** the dissected landscape characteristic of the northern Blue Mountains, **(B)** a sampled site in the 'Cool Moist Forest', **(C)** a site in the 'Cool Wet Forest', and **(D)** a site in the 'Warm Dry Forest' potential vegetation classifications (Powell et al. 2007). Photo credits: Laura Platt.

The study area is characterized by a continental climate with warm and dry summers, and cold winters, with the majority (90%) of precipitation occurring during the winter months in the form of snow. Across the study area, average monthly temperatures range from 15.5 to 18.3°C in July (15.6 to 17.1°C) and -3.7 to -0.5°C (-4.7 to -2.2°C) in January at the Jubilee Lake (and at the Beaver Creek) sites (PRISM, 2019). The average annual precipitation ranges from 628.2 to 1343.7 mm at Jubilee Lake and 711 to 898mm at Beaver Creek (PRISM, 2019; Western Regional Climate Center, 2019).

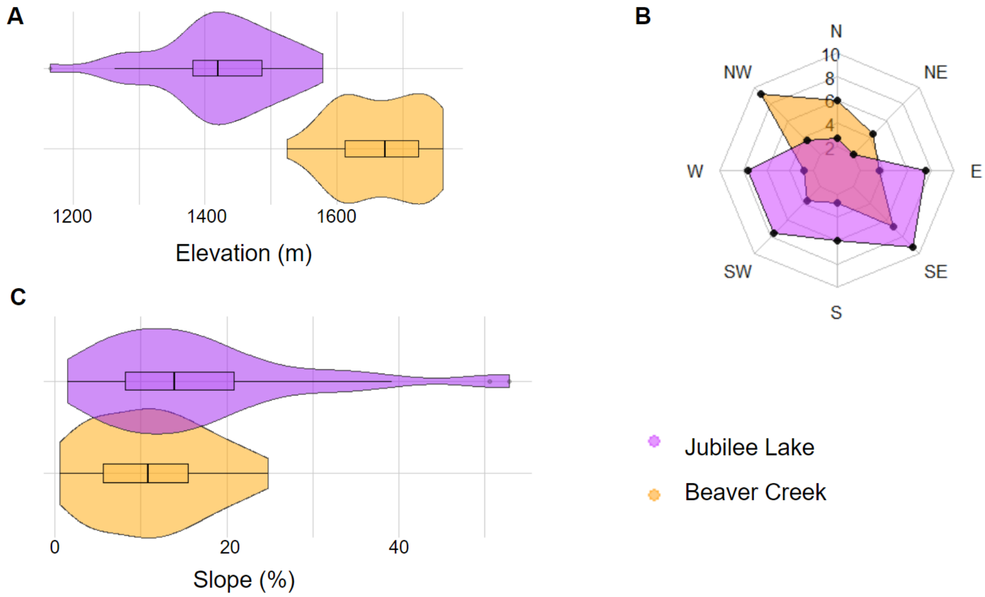


**Figure 3:** Topographic distribution of sampled plots in the Jubilee Lake and Beaver Creek study sites by **(A)** elevation, **(B)** aspect, and **(C)** slope. Aspect scale is from 0 plots at the center to 10 plots at the outside. n=29 for Beaver Creek, and n=38 for Jubilee Lake.

## 3.2 SAMPLING APPROACH

A multi-proxy sampling scheme was used to reconstruct historical patterns of fire and tree establishment in the northern BME (Agee 1996). The data analyzed in this study were derived from samples collected just prior to acquisition of the present JFSP funding. Samples from tree ring fire scars and tree ages were processed to quantify estimates on number and percent of scarred trees per year and tree density over time, respectively. Additionally, short saplings were harvested and processed to correct for coring height (i.e. unknown number of years missed due to core extraction above root collar) using size-age regressions.

In order to capture as much of the variability in fire activity across the landscape as possible, a stratified random sampling approach was used to allocate the sampling efforts across patches with distinct forest structure (O'Hara et al. 1996), as delineated and interpreted from aerial photos from the 1930s (i.e. prior to intensive and widespread fire suppression efforts; Hessburg et al. 1999; **Figure 4**). Fundamentally, our goal was to use structural diversity as a proxy to ensure a comprehensive dendroecological sample across the range of disturbance and successional conditions within our study landscapes. Each patch was assigned a structural class (O'Hara et al. 1996; **Table 1**) based on photo-interpreted stand structural attributes and dendroecological sampling effort was allocated according to the proportional area of each structure class in each subwatershed. In order to capture a diversity of disturbance histories, we sampled sites with a variety of structural classes represented. Dendroecological sampling intensity was scaled with the complexity of inferred disturbance history for each structural type (e.g. more samples in old forest multistory than young even-aged; **Table 1**). To reconstruct both fire history and severity within each sample patch, we combined intensive sampling of age structure and fire scar samples across a spatially distributed network of plots. In order to capture pre-fire exclusion forest composition and structure, the field crew avoided sampling in areas that, since the aerial-photo interpretative work, were known to have experienced timber harvest or fire.

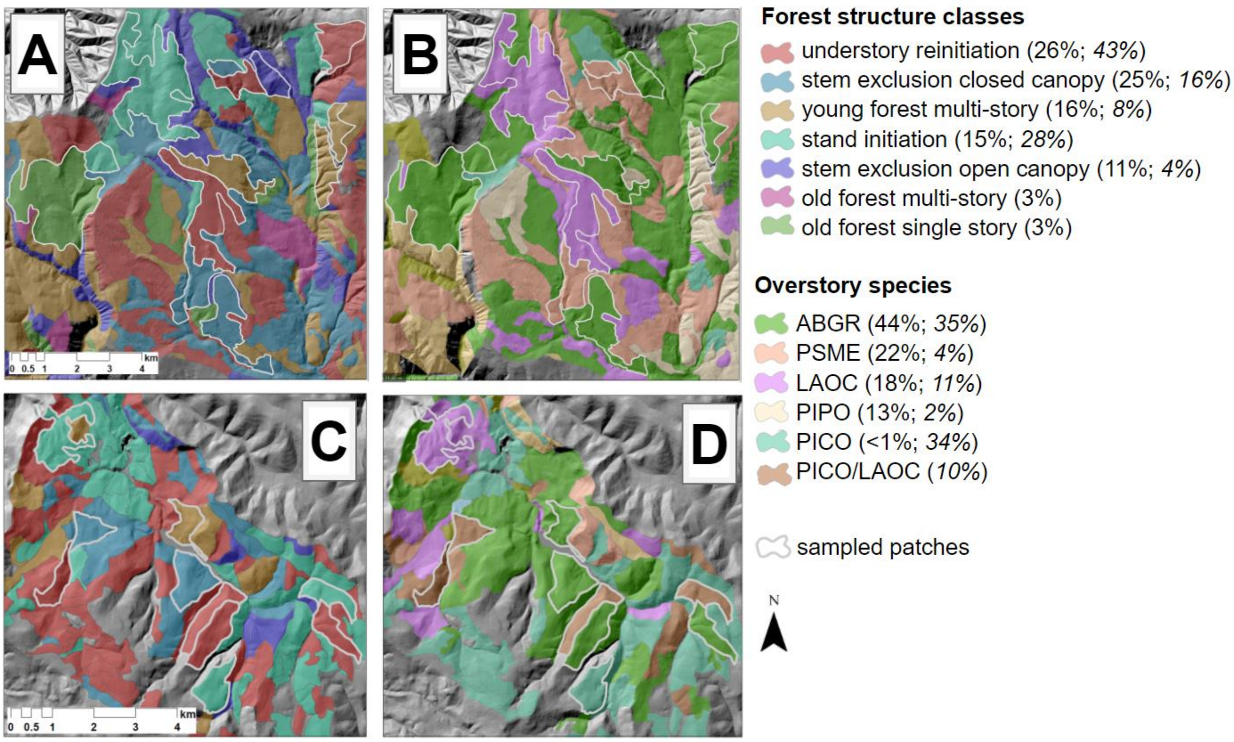



**Figure 4:** Sampled patches in the Jubilee Lake (top row) and Beaver Creek (bottom row) subwatersheds stratified by forest stand structure (**A** and **C**) and dominant overstory species composition (**B** and **D**), as interpreted from historical aerial imagery (Hessburg et al. 1999). Percent area in the subwatersheds represented by each structural class and overstory species are shown. Grand fir (ABGR), subalpine fir (ABLA), western larch (LAOC), lodgepole pine (PICO), Engelmann spruce (PIEN), ponderosa pine (PIPO), and Douglas-fir (PSME). Forest structure classes and overstory species reconstructed outside sampling areas are shown for landscape context.

## 3.3 FIELD METHODS

To characterize the age structure of plots within sample patches, we extracted increment cores from all trees expected to have established prior to fire exclusion (defined here as ≥10cm diameter at breast height [DBH]), increment cores were extracted from targeted trees in two diameter size classes: 'large' and 'small'. Due to high intra-patch variation in structure and composition, the specific diameter range and thresholds assigned to 'large' and 'small' trees were determined by the existing tree species composition and size (DBH) structure at the plot level. Cores were collected in each plot from the 15 (ten 'large' and five 'small') closest trees to each plot center. Species and DBH of each cored tree were recorded, and the distance from plot center to the farthest tree sampled was measured for both the large and small size class plots in order to calculate plot area (needed to calculate tree density). In order to avoid missing growth rings and attain the most accurate estimate of establishment dates, coring of trees was conducted as close to the ground as possible and coring height was recorded. Increment cores were checked in the field to ensure presence of the tree's pith, or proximity to pith (i.e. presence of central rings estimated to be within five years of pith). If the tree's pith was missed, another core was obtained from the same tree and the best core out of up to five attempts was kept. In cases where a tree was too rotten (approximately 15% of sampled trees) to produce useful information, a substitute core of the same tree species and similar DBH class was collected from outside the plot.

**Table 1.** Structural types along a successional gradient (O'Hara et al. 1996) and respective sampling intensity are listed in increasingly higher structural complexity. Number of plots to be sampled per structural patch type was predetermined as a function of structural complexity with more plots in more complex structural types.

| **Structural type** | **Description** | **# sample plots/patch** | **# tree cores/patch** |
|---|---|---|---|
| Stand initiation | Recently disturbed; dominated by a single cohort of seedlings/saplings | 2 | 30 |
| Stem exclusion, closed canopy | Dense forest of small trees, often with a single cohort | 2 | 30 |
| Stem exclusion, open canopy | Open forest with small trees of similar size | 3 | 45 |
| Understory reinitiation | Relatively closed canopy forest comprised by patches with different age classes, two or more cohorts | 3 | 45 |
| Young forest, multistory | Low density forest dominated by small and medium sized trees. Intermediate to high complexity | 4 | 60 |
| Old forest, single story | Old forest with single size class, one or more cohorts present | 4 | 60 |
| Old forest, multistory | Forest comprised by patches with different age and size classes, including patches with large, old trees | 4 | 60 |

To correct for missing tree rings due to coring height, ca. 10 saplings (<4cm DBH) per species were harvested at each of the two sites, processed in the lab (see below), and used to correct tree-establishment estimates via size-age regression models. These saplings were harvested from areas under environmental conditions (e.g. open canopy for shade-intolerant species) similar to those expected to have been experienced during the establishment of the sampled adult trees (Villalba and Veblen 1997).

Sampling of fire scars was conducted opportunistically when hiking to and from the age structure plots, as well as during extensive searches within sampled patches and along patch boundaries. Fire scars were collected with a chainsaw in partial (non-destructive) cross-sections, and in order to minimize impact on living trees, dead trees were targeted for sampling where possible. Intact fire scars were rare at Jubilee Lake (33% of sampled trees), where most scarred trees encountered were rotten grand fir. Intact fire scars were more common at the Beaver Creek site, found typically on western larch or ponderosa pine. Where possible, between 5-10 partial cross-section samples were collected per patch at both sites.

## 3.4 SAMPLE PROCESSING/DATA ANALYSIS

All dendroecological samples were processed in the lab using standard procedures (Stokes and Smiley 1968). Samples were cross-dated visually using the list-year method (Yamaguchi 1991) and statistically if necessary with CDendro (Cybis Elektronik, 2010). Master tree ring chronologies for each species sampled were created in order to increase accuracy in statistical crossdating. To correct for core samples where pith was missed, the Duncan method was used to estimate the number of missing rings to pith (Duncan 1989). The establishment dates of trees that could not be crossdated, and/or had a suggested correction of Duncan >30 years, and/or were missing central rings (4% of all samples) were modeled using a species-specific, local size-age regression (within forest patch). At the time of core extraction, 93% of the sampled trees were alive.

For analyses, tree establishment dates were binned by decade to account for errors in true age caused by deviations from true pith and sampling height, despite corrections for coring height and missing pith. As tree establishment patterns at the plot-scale were largely congruent/consistent among plots per patch, and because fire histories were most robust at the patch scale, tree age structures are reported at the patch scale. To identify synchronous pulses of tree establishment , cohort peaks were identified for each species per patch using a modified version of CharAnalysis that has been adapted for tree ring establishment data (Higuera 2009, Tepley & Veblen 2015, Andrus et al. 2018).

Fire events were attributed to an individual patch based on fire scar samples scarred found within each patch boundary or, in the case of Jubilee Lake where fire scarred trees were scarce in some patches, a maximum distance of 276m from the closest age structure plot to the patch. Following Tepley and Veblen (2015), this distance was obtained from the median value of the distance distribution between cross-section samples to closest age structure plots at this site. For patches with tree establishment data, but lacking fire scar evidence entirely (four of 13 patches at Jubilee Lake, none at Beaver Creek), tree establishment peaks and fire scar samples from neighboring patches were used to identify likely fire dates. Where present, fire barriers (e.g. abrupt topographic features) were also considered in these attributions. Fire dates were compiled into FHX file format and analyzed with Fire History Analysis and Exploration System (FHAES) and graphed with the burnr package in the R statistical environment (Brewer et al. 2016; Malevich et al. 2018).

To quantify historical fire frequency, mean and median fire intervals for each patch were computed using traditional aggregation filters of fire-scarred trees, including all fire years (composited by patch) and widespread fire years (years in which at least 30% of all fire recording trees [i.e. trees that had previously recorded at least one fire before that date] recorded a fire Swetnam and Betancourt 1990; Veblen et al. 2000). To reduce bias in fire frequency statistics caused by inclusion of small fires or scars caused by non-fire agents, only fire events recorded in at least two patches were included in calculation of fire frequency statistics. Only scar-to-scar intervals were used. To quantitatively reconstruct historical fire severity, event-level fire severity metrics and classes were calculated following methods in Tepley and Veblen (2015) and Naficy (2016), where the age structure and fire record of each patch are used to quantify the rate of loss in forest stand density with each fire event. Fire severity was reconstructed for Jubilee Lake only, as analyses for Beaver Creek are currently underway.

## 4. RESULTS

Across three subwatersheds, 67 age-structure plots were sampled in 23 unique forest patches representing six different forest structural types (**Table 2, Figure 5**). In total 1005 tree core samples, 94 saplings, and 164 fire scar partial cross-sections were collected to reconstruct patch-level fire frequency and severity in MMC patches across a range of environmental settings from the margins of dry mixed conifer forest to cold forest vegetation types.

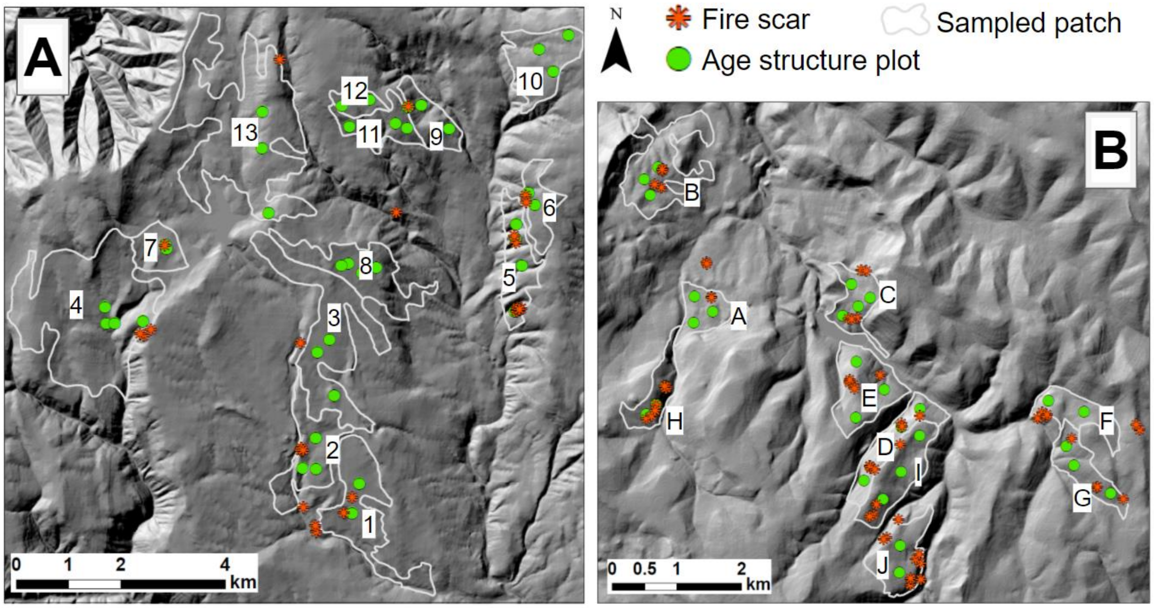



**Figure 5.** Map of sampled patches with age structure plots and fire scars across the **(A)** Jubilee Lake and **(B)** Beaver Creek subwatersheds. Patches are labeled with a unique ID, in order of increasing elevation (1=lowest, 13=highest for Jubilee Lake; and A=lowest, J= highest for Beaver Creek).

### 4.1 HISTORICAL FIRE FREQUENCY AND OCCURENCE

At the Jubilee Lake site 48 fire scars were identified and dated on 29 crossdated partial cross-section samples (**Figure 6**). There was an average of 1.7 scars per sample (maximum 4), with 52% of the samples having only one scar. Of the trees sampled for partial cross-sections, 52% were alive at the time of sampling. By far ponderosa pine accounted for the largest portion (62%) of fire scar samples, followed by Douglas-fir (14%), western larch (14%), lodgepole pine (7%), and grand fir (3%). The initial sample set of 102 partial cross-sections consisted of approximately 45% Grand fir, but due to rot and high dating uncertainty of fire years, most of these were excluded from further analysis. Fires at the Jubilee Lake site were recorded from 1765 to 1958, and were most frequent during the second half of the 19$^{th}$ century (1869-1883). Few events were recorded prior to 1800 and the chronology is mostly fire-free after the 1900s; less than 13% of all crossdated fire scars were formed after 1902 (**Figure 6**). In the study area, the availability and quality of fire scar samples generally decreased with elevation. Due to a scarcity of fire scar evidence, ca. half of the patches (six out of 13) did not have enough scar to scar data (one or less recorded fire events) to calculate fire frequency metrics (i.e. intervals).

**Table 2.** Summary and stratification of sampling effort by forest structure in the two study sites (Jubilee Lake, JL and Beaver Creek, BC). Number of patches in each site (i.e. subwatershed) was proportional to the representation of each structural type in the site and number of plots in each patch was predetermined as a function of structural complexity with more plots in more complex structural types.

| **Patch Structural Type** | **%Area** | | **#Patches** | | **#Plots** | | **#Tree Cores** | | **Cross-section Samples** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | JL | BC | JL | BC | JL | BC | JL | BC | JL | BC |
| Stand initiation | 15 | 28 | 2 | 3 | 5 | 7 | 75 | 105 | 12 | 28 |
| Stem exclusion open canopy | 11 | 4 | 1 | 0 | 3 | 0 | 45 | 0 | 4 | 0 |
| Stem exclusion closed canopy | 25 | 16 | 3 | 2 | 7 | 6 | 105 | 90 | 20 | 11 |
| Understory reinitiation | 26 | 43 | 3 | 4 | 9 | 12 | 135 | 180 | 27 | 31 |
| Young forest multistory | 16 | 8 | 3 | 1 | 10 | 4 | 150 | 60 | 24 | 6 |
| Old forest multistory | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Old forest single story | 3 | 0 | 1 | 0 | 4 | 0 | 60 | 0 | 15 | 0 |
| | Site total: | | 13 | 10 | 38 | 29 | 570 | 435 | 102 | 76 |
| | **Grand total:** | | | **23** | | **67** | | **1005** | | **178** |

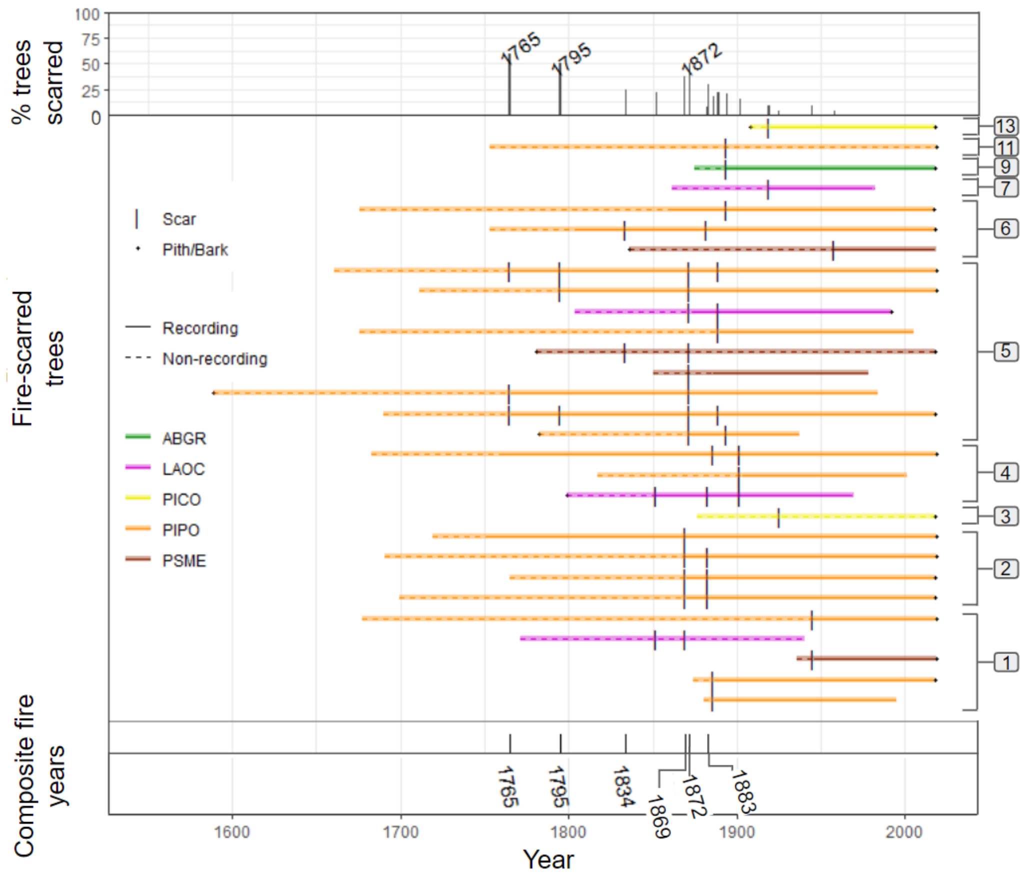



**Figure 6.** Chronologies of fire scars for the Jubilee Lake site at the tree scale. Each horizontal line represents one partial cross-section sample, colored by species (ABGR = grand fir, LAOC = western larch, PICO = lodgepole pine, PIPO = ponderosa pine, and PSME = Douglas-fir). Brackets on the right y axis group individual scarred trees (sampled cross-sections) by patch. Patches are in order of increasing elevation (1=lowest, 13=highest) and correspond to patches numbered in **Figure 5** (notice that cross-sections were not datable in patch #s 8, 10 or 12). A composite fire chronology at the base of the figure shows fire years where at least 25% of all recording trees recorded fire and at least two trees were scarred. Composite fire event years are: 1765, 1795, 1834, 1869, 1872, and 1883.

At the Beaver Creek site fire evidence was more common and samples were of higher quality than at the Jubilee Lake site, with 90 fire scars identified on 64 crossdated partial cross-sections (**Figure 7**). Similar to sample statistics from Jubilee Lake, there was an average of 1.4 scars per sample (maximum 4), with 61% of the samples having only one scar. Of the trees sampled for partial cross-sections, 75% were alive at the time of sampling. Species composition varied substantially from Jubilee Lake, where western larch accounted for the largest portion (81%) of fire scar samples, followed by Douglas-fir (8%), ponderosa pine (6%), and lodgepole pine (5%). Fires at the Beaver Creek site were recorded from 1635 to 1960, and were generally common in the record in the latter half of the 18$^{th}$ and throughout the 19$^{th}$ century (1748-1892). Few events were recorded prior to 1700 and, as in Jubilee Lake, the chronology is largely fire-free after 1900; less than 6% of all crossdated fire scars were formed after 1900 (**Figure 7**).

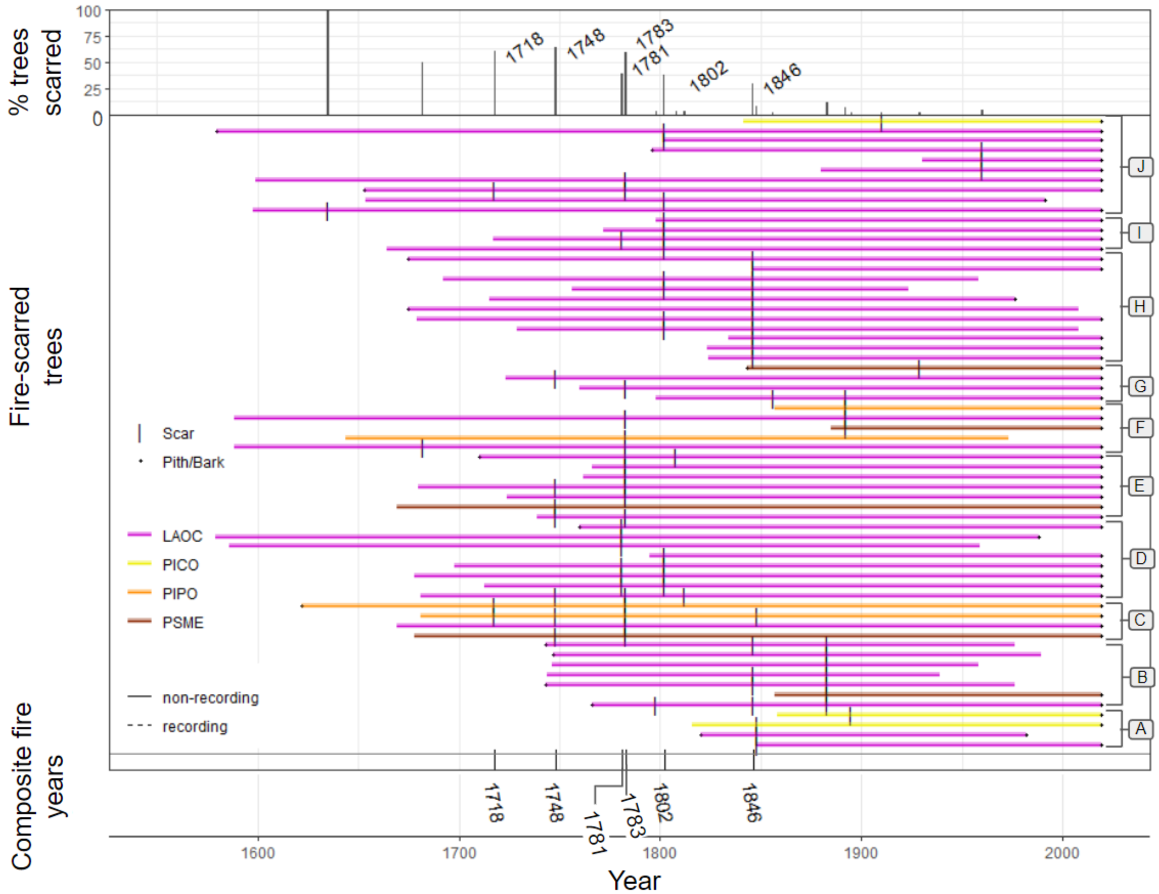



**Figure 7.** Chronologies of fire scars for the Beaver Creek site at the tree scale. Each horizontal line represents one partial cross-section sample, colored by species (LAOC = western larch, PICO = lodgepole pine, PIPO = ponderosa pine, and PSME = Douglas-fir). Brackets group individual scarred trees (sampled cross-sections) by patch. Patches are in order of increasing elevation (A=lowest, J=highest) and correspond to patches numbered in **Figure 5**. A composite fire chronology at the base of the figure shows fire years where at least 25% of all recording trees recorded fire and at least two trees were scarred. Composite fire event years are: 1718, 1748, 1781, 1783, 1802, and 1846.

At the subwatershed scale, a total of 30 fire events were reconstructed in the 13 sampled patches at Jubilee Lake. Of these 30 events, successfully cross-dated fire scar samples were used to identify 23 (77%) events and were found in nine of the 13 sampled patches (69%; **Figure 8A**). The remaining seven events (23%) in five patches lacked fire scar samples (fire scar evidence was found in all five of these patches, but the samples were all rotten) and thus were attributed fire dates by evaluation of the co-occurrence of tree establishment peaks and closely matching fire dates from fire scar samples in neighboring patches (**Figure 8A**). Out of the nine patches that recorded and had intact fire scars (69%), the mean and median number of fire events were ca. 2.5 and 2, respectively, whereas ca. 1.4 and 1 events were recorded for the remaining patches.

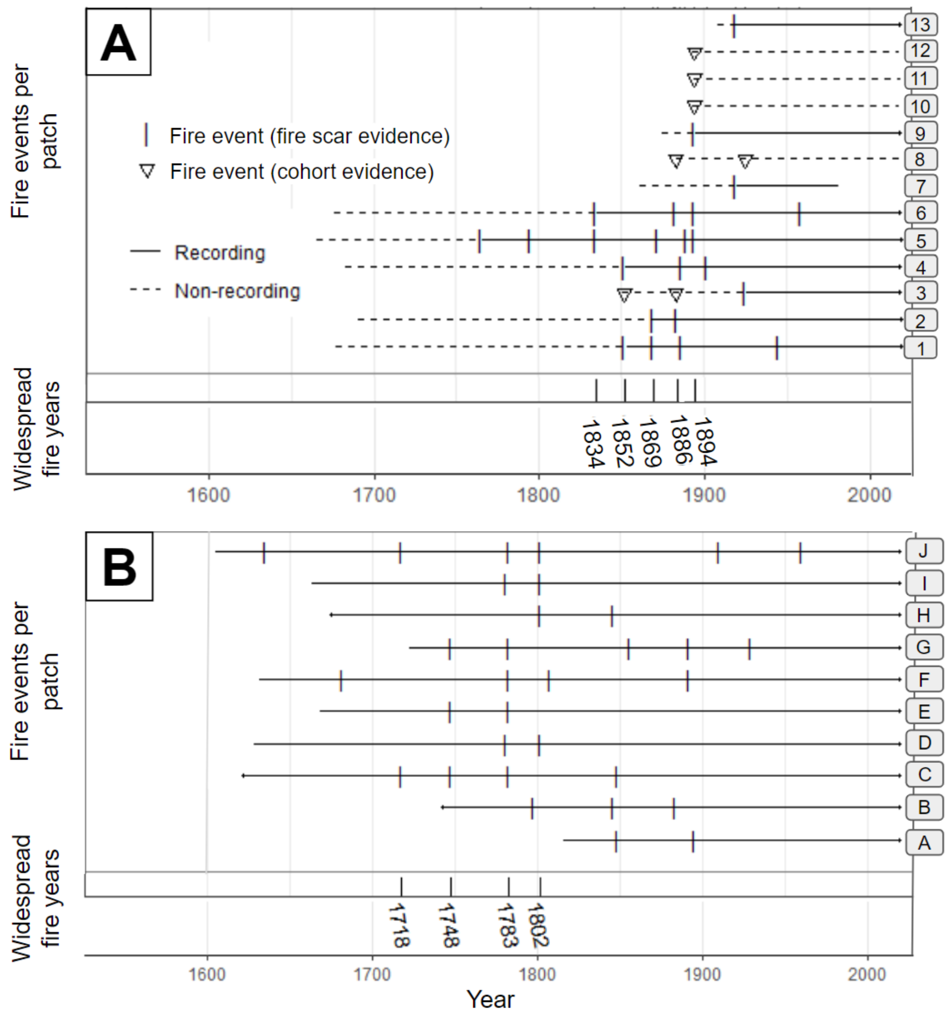



**Figure 8.** Subwatershed-scale (by patch) fire demography charts for the **(A)** Jubilee Lake and **(B)** Beaver Creek sites. Each horizontal line shows a composite of fire events for a forest patch. Patches are in order of increasing elevation (1=lowest, 13=highest for Jubilee Lake, and A=lowest, J=highest for Beaver Creek) and correspond to patches labeled in **Figure 5**. Fire events are recorded in each patch as solid vertical black lines. For Jubilee Lake, open triangles are fire years that were attributed to a patch based on neighboring patch fire scar evidence, and the establishment peak of a cohort of regenerating trees. A subwatershed-scale composite plot at the base of the figure shows widespread fire years: fire years where at least 30% of all patches recorded a fire event in that year, with a minimum of two patches recording the fire. Widespread fire years for Jubilee Lake are: 1834, 1852, 1869, 1886, 1894, and for Beaver Creek: 1718, 1748, 1783, 1802.

At the subwatershed scale for the Beaver Creek site, a total of 32 fire events were reconstructed in the 10 sampled forest patches (**Figure 8B**). Intact samples were found in all of the sampled patches at this site, and thus there was no need to attribute fires based on cohorts and neighboring patch fire scar evidence. The mean and median number of fire events per patch over the reconstructed (1635 to 1960) period were ca. 3.2 and 2.5, respectively.

Fine-scale fire patterns were observed in both sites, particularly at Jubilee Lake, where in many years there was evidence of fire in one patch and no evidence of fire in an adjacent patch. At the Jubilee Lake site, the widespread fire years were: 1834, 1852, 1869, 1886, and 1894, with no single fire year recorded in all patches (**Figure 8A**). The most widespread fire year was recorded in six (46% of) patches in 1894, after which no widespread fires were recorded. At the

Beaver Creek site, the widespread fires were 1718, 1748, 1783, and 1802 (**Figure 8B**). The most widespread fire year at this site was recorded in five (50% of) patches in 1783. The second most widespread fire at this site was recorded in 1802 in four patches, after which no widespread fires were recorded.

Across patches in both sites, fires were more frequent than anticipated, with mean fire intervals at Jubilee Lake ranging from 14 to 42 years (median: 14 - 48 years) with an average patch size of approximately 200 ha, and mean fire intervals at Beaver Creek ranging from 21 to 70 years (median: 21 - 84 years) with an average patch size of approximately 70 ha (**Figure 9**). Large variability was found between individual minimum and maximum intervals of individual events amongst patches at both sites, where the minimum fire interval was five years, and the maximum was 64 years at Jubilee Lake, and the minimum fire interval was 19 years, and the maximum was 108 years at Beaver Creek. Interestingly, the minimum and maximum fire interval for Beaver Creek was recorded in the same patch, which is also the highest elevation patch at this site (patch J; **Figure 9**). There is no obvious correlation between mean/median fire intervals and the moisture gradient (precipitation as snow in millimeters), however the two longest fire intervals calculated for Beaver Creek forest patches are on the wetter end of the gradient (**Figure 9**)

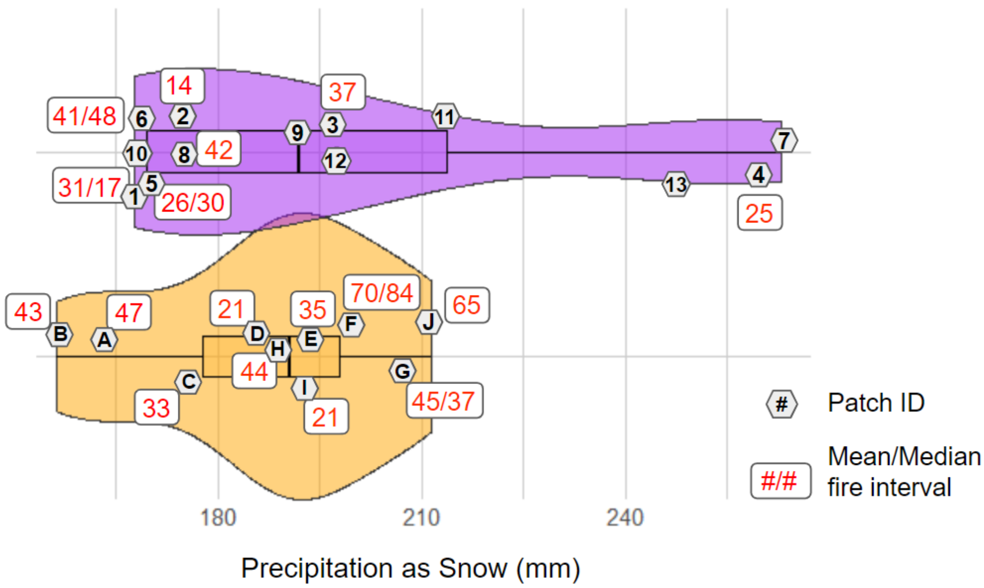



**Figure 9.** Violin boxplots of sampled patches shown along a moisture gradient with per-patch mean/median fire intervals for the two sites, Jubilee Lake (upper; n=13) and Beaver Creek (lower; n=10). Mean fire intervals at Jubilee Lake range from 14 to 42 years (median: 14 - 48 years), and mean fire intervals at Beaver Creek range from 21 to 70 years (median: 21 - 84 years). Patches are labeled in order with increasing elevation (1=lowest, 13=highest for Jubilee Lake, A=lowest, J=highest for Beaver Creek). Due to lack of fire scar evidence, median/mean fire intervals could be calculated for only seven of 13 patches at Jubilee Lake. Where there is only one value provided for the fire interval, the mean and median were the same. Climate data were calculated using ClimateNA (Wang et al. 2016) for the reference normal 1961-1990 period. The x axis is winter precipitation as snow in millimeters. Median value (vertical black bar) is 192mm for Jubilee Lake and 190mm for Beaver Creek.

### 4.2 – HISTORICAL FIRE AND TREE ESTABLISHMENT

The majority (66%) of reconstructed tree establishment in forest patches at the Jubilee Lake site occurred between 1880 and 1930 (**Figure 10A**) though peaks in establishment were identified in nearly every decade and varied in frequency and timing by patch (**Figure 10B**). Tree establishment abundance was dominated by grand fir (59% of cores collected) regardless of decade or patch, and post-fire establishment of grand fir cohorts was common (**Figure 10B**). Grand fir dominated the post-fire tree recruitment in nine (53%), and was present in 16, of the 17 post-fire cohorts identified (i.e. establishment peaks within the same decade, or decade following, a fire attributed to that patch). Establishment peaks not associated with fire were not as common as post-fire peaks, but were observed in five of 13 patches and comprised eight of 25 (32%) total identified establishment peaks (**Figure 10B**). Establishment of other tree species over the time series, including Engelmann spruce (17% of cores) and western larch (13% of cores) were also common. A minor component of recorded tree establishment included Douglas-fir (5%), lodgepole pine (4%), ponderosa pine (2%), and subalpine fir (1%).

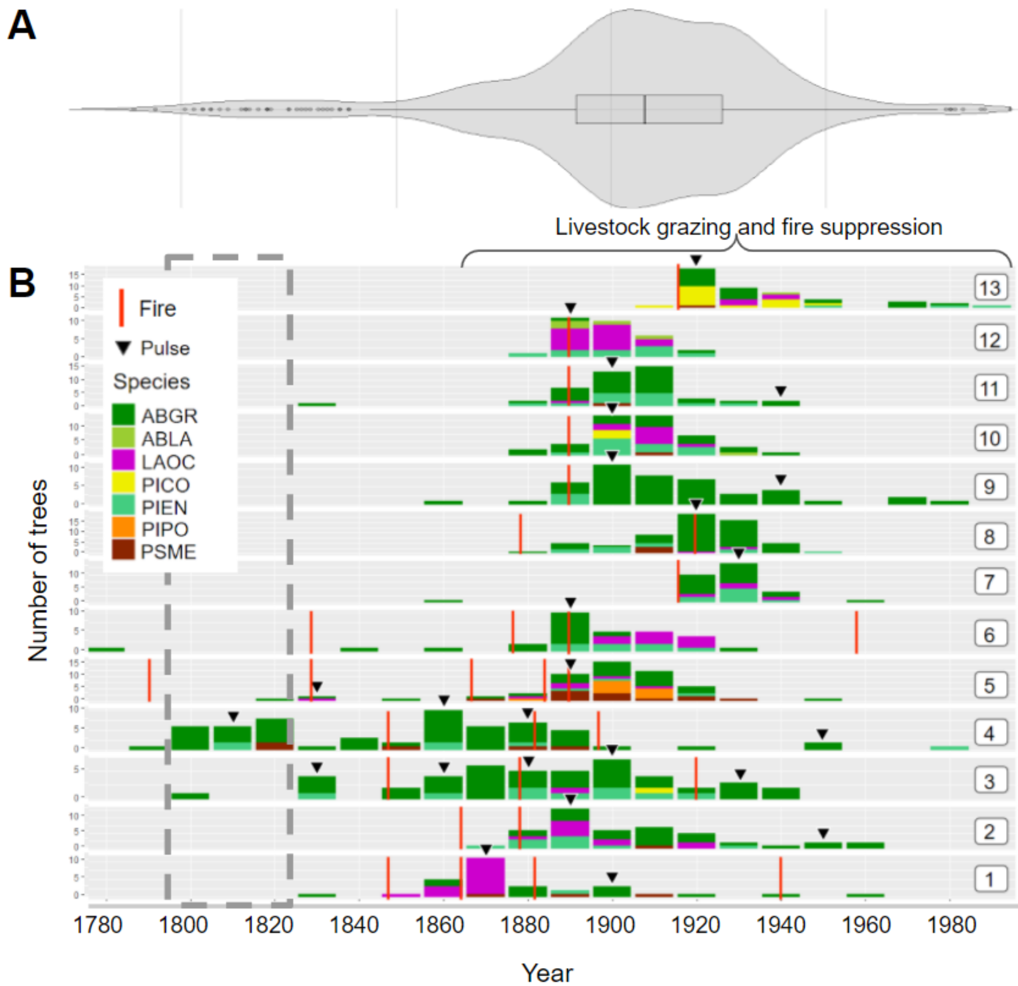



**Figure 10.** (**A**) Violin boxplot of combined tree establishment dates (n=569) across all patches at the Jubilee Lake site. Median establishment date for all trees cored is 1908 (solid black bar), lower quartile is 1892 and upper quartile is 1926. (**B**) Establishment demography and fire events for each of the 13 sampled patches across moisture availability (elevation). Patches are in order of increasing elevation (1=lowest, 13=highest) and correspond to patches numbered in **Figure 5**. Establishment dates are binned by decade. Black triangles above bars indicate significant pulses in tree establishment as identified using a modified version of CharAnalysis (Higuera 2009; Andrus et al. 2018). Species abbreviations are as follows: Grand fir (ABGR), subalpine fir (ABLA), western larch (LAOC), lodgepole pine (PICO), Engelmann spruce (PIEN), ponderosa pine (PIPO), and Douglas-fir (PSME). Three PIPO trees, not shown in the figure above, established in 1520, 1536 and 1570 in the patch with other PIPO

present. Vertical dashed rectangle captures the early 19th century fire gap reported in dry ponderosa forests in the northern BME by Heyerdahl et al. 2001.

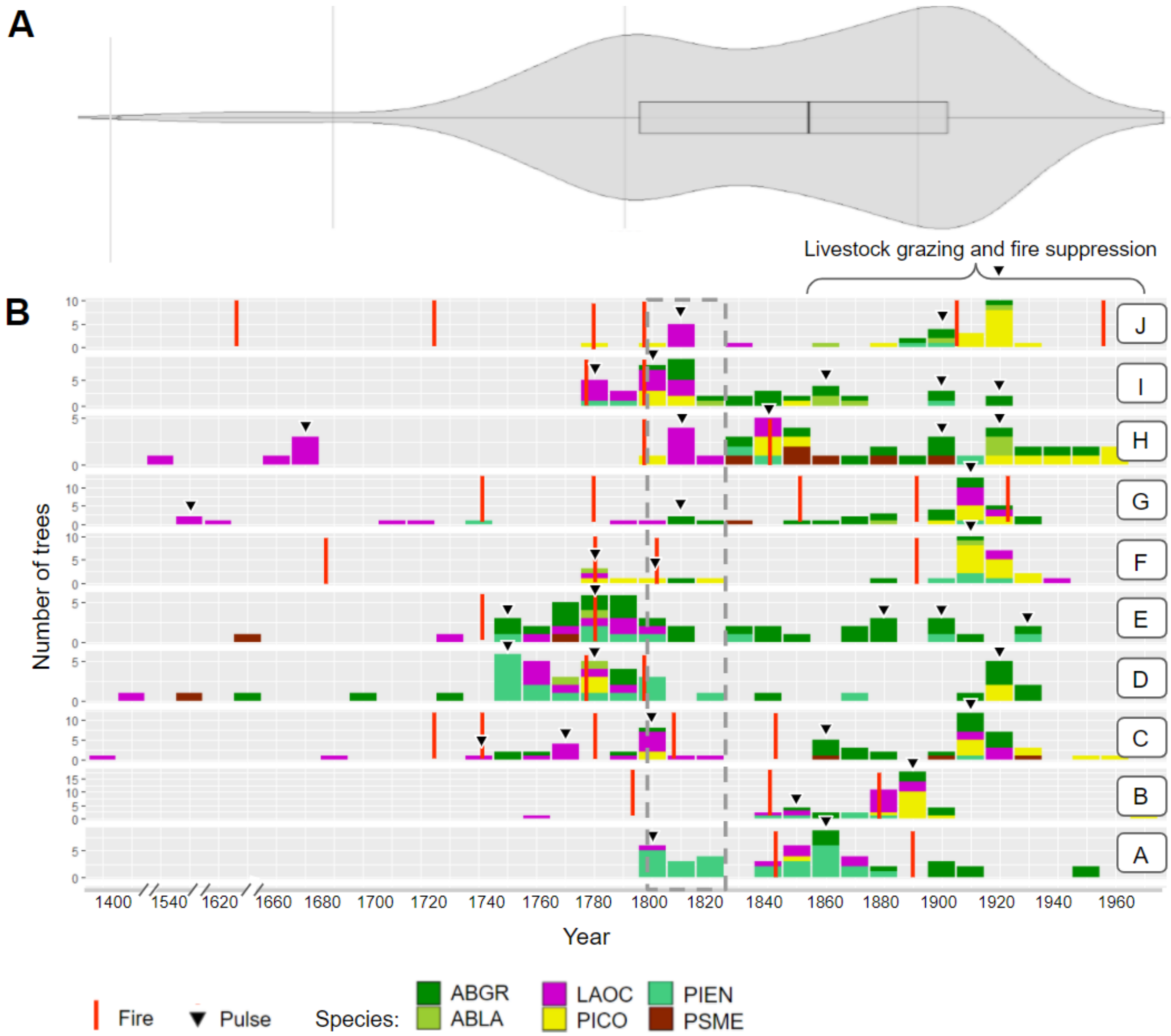


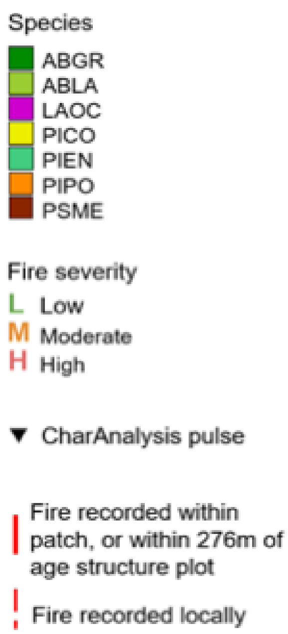

**Figure 11.** (**A**) Violin boxplot of establishment dates (n=426) across all patches at the Beaver Creek site. Median establishment date for all trees cored is 1863 (solid black bar), lower quartile is 1805 and upper quartile is 1910. (**B**) Establishment demography and fire events for each of the 10 sampled patches. Patches are in order of increasing elevation (A=lowest, J=highest) and correspond to patches labeled in **Figure 5**. Establishment dates are binned by decade. Black triangles above bars indicate significant pulses in tree establishment as identified using a modified version of CharAnalysis (Higuera 2009; Andrus et al. 2018). Species abbreviations are as follows: Grand fir (ABGR), subalpine fir (ABLA), western larch (LAOC), lodgepole pine (PICO), Engelmann spruce (PIEN), and Douglas-fir (PSME). Vertical dashed rectangle captures the early 19th century fire gap reported in dry ponderosa forests in the northern BME by Heyerdahl et al. 2001.

The reconstructed tree establishment at the Beaver Creek site exhibited a largely bimodal distribution, with the majority of trees (53%) establishing in two separate 40-yr periods over the nearly 600-year record (1780-1818 and 1890-1929; **Figure 11A**). Though, similar to Jubilee Lake, establishment peaks were identified in nearly every decade and exhibited variability in frequency and timing by patch. Grand fir and western larch were the two most abundant trees species in the tree establishment reconstruction at the Beaver Creek site (33% and 25% of cores sampled, respectively; **Figure 11B**). Lodgepole pine (19%) and Engelmann spruce (16%) were also somewhat abundant in the record. A minor component of recorded tree establishment included subalpine fir (4%) and Douglas-fir (3%). Post-fire establishment of all tree species was common, including grand fir cohorts. Establishment peaks not associated with fire were not as common as post-fire peaks, but were observed in eight of 10 forest patches, and comprised 17 of 36 (47%) total identified establishment peaks (**Figure 11B**).

### 4.3 – HISTORICAL FIRE SEVERITY AND TREE ESTABLISHMENT

Fire severity exhibited fine-scale variation over space and time in the Jubilee Lake study area. Adjacent forest patches often burned with different severities in the same year (e.g. patch #s 10, 6 and 5 in **Figure 12**). Likewise, fire severity within patches varied over time with different fire events (e.g. patch #s 1, 2 and 3 in **Figure 12**). Of the 30 fires reconstructed at Jubilee Lake, six (20%) were calculated to be of low severity, 14 (47%) were moderate severity, and ten (33%) were high severity. A majority of the patches (77%) experienced at least one high severity fire, though no single high-severity fire event was recorded across more than four sampled patches. Of the 33 fires reconstructed at Beaver Creek, six (18%) were calculated to be of low severity, 15 (45%) were moderate severity, and nine (27%) were high severity. A majority of the patches (70%) experienced at least one high severity fire, though no single high severity fire event was recorded across more than three sampled patches.

Presence of fire was also apparent throughout the study area on living, fire-scarred (but rotten) trees, and many patches that experienced a high severity fire also experienced either a low or moderate severity fire, or both. This suggests high variability of fire severity over time across much of the landscape. Variation in post-fire cohort species composition was also high, and overall there is not a systematic pattern in the composition-severity relationship (e.g. post-fire cohorts of shade-tolerant grand fir were common following both low, moderate, and high severity fires).



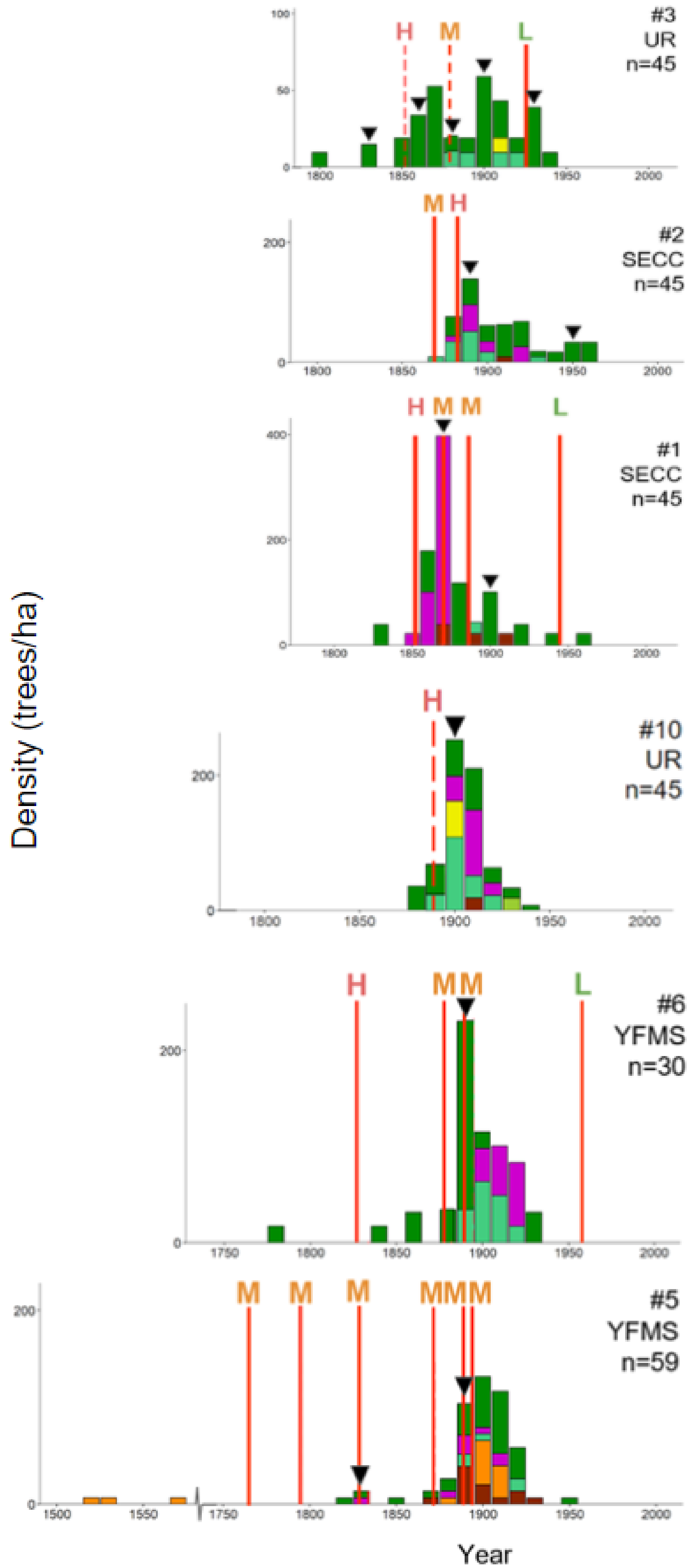




**Figure 12.** Fire history and age structure of a subset of sampled patches at Jubilee Lake. The patch number and structural type, as well as the number of pith dates (i.e. core samples) are indicated in the upper right corner of each panel. Fire scars found on partial cross-sections within 276m (median value of distance distribution) of the closest age structure plot and fire events attributed to a patch based on cohort data and neighboring patch fire scars (i.e. fires recorded locally) are represented by solid red lines, and dashed red lines, respectively. The cohort peaks and severity of individual fires are also indicated. Species and structural type abbreviations are as follows: Grand fir (ABGR), subalpine fir (ABLA), western larch (LAOC), lodgepole pine (PICO), Engelmann spruce (PIEN), ponderosa pine (PIPO), and Douglas-fir (PSME); old forest single story (OFSS), stem exclusion closed canopy (SECC), stem exclusion open canopy (SEOC), stand initiation (SI), understory reinitiation (UR), and young forest multistory (YFMS).

## 5. DISCUSSION

Historical fire occurrence, tree establishment, and fire severity patterns were highly variable over time and space at a fine scale (hundreds of hectares) in the MMC forests of the Jubilee Lake and Beaver Creek subwatersheds in the Northern Blue Mountains (e.g. **Figures 10B, 11B, &12**). Such fine-scale variability supports the perspective of high historical heterogeneity at the patch and landscape scales (Hessburg et al. 2015). Our findings are also consistent with the meso-scale patch heterogeneity characteristic of mixed-severity fire regimes that result from hybrid or interacting top-down (climate) and bottom-up (topography) controls (Perry et al. 2011).

In these MMC forests the historical fire patterns appear to be even more fine-scale (i.e. less spatially synchronous across the study area) than in other fire history studies in mixed-severity fire regime forests (e.g. Tepley and Veblen 2015; Heyerdahl et al. 2019). This may be partly due to scarcity of intact fire scar evidence, and dominant trees (mostly grand fir) being poor fire recorders within the study area, as this study area is substantially more productive (wetter) than sites in these previous studies in NE Oregon (Heyerdahl et al. 2001). Nonetheless, a larger fire scar sample depth might instead have confirmed the high variability and fine-scale patterns found in this study. The highly dissected topography typical of the BME, where steep drainages and rocky slopes interrupt the continuity of surface fuels and isolate forest patches, may limit fire spread, also contributing to these fine-scale patterns (Stine et al. 2014). Additionally, spatially heterogeneous forest stand structure may have played an important role in influencing historical fire behavior and the spatial variation and arrangement of subsequent post-fire forest patches. The variable nature of the historical fire patterns in these forests would have likely perpetuated these disturbance and forest development processes over time, with each successive fire reinforcing, subdividing, or overwriting the forest structural patterns at fine scales (Tepley et al. 2013; Taylor et al. 2020).

In patches with two or more events, fires were more frequent than anticipated within the MMC forest and mean fire intervals, where calculated, did not deviate much across moisture gradients within the study area (**Figure 9**). Furthermore, and in the case of the Jubilee Lake study area, the presence of small, high severity fires was common across this 9,300ha landscape, with no single high severity event recorded in all patches sampled. Notably though, in the Jubilee Lake site, intact fire scar samples decreased with increasing elevation (e.g. patch #s 5, 6 and 10 in **Figures 10B & 12**), including the six patches that recorded just a single, recent high severity fire that may have erased earlier fire evidence. These patches were at relatively high elevation within the subwatershed, and on the cooler/wetter end of the climatic gradient within the study area that fits the climate-limited, high severity fire regime model (Schoennagel et al. 2004). However, the frequent fire reconstructed in most (seven of thirteen) patches at Jubilee Lake, and in all ten patches at Beaver Creek, is counter to previous estimates that suggest fires were relatively infrequent (i.e. 50-200-year return intervals) in these mid-elevation, moist forests (Agee 1996; Brown et al. 2004). The findings in this study are consistent with more recent regional syntheses (e.g. Stine et al. 2014) and recent studies within the BME and in drier surrounding forests (e.g. Heyerdahl et al. 2001, Johnston et al. 2016, Merschel et al. 2018) that document relatively frequent fires in DMC to MMC forests.

Few events were recorded prior to 1800 in the Jubilee Lake site (**Figures 6 & 8A**), which may be due to lack of intact, dead and older recorder trees to reconstruct earlier fires. The reconstructed fire record extends back another century (ca. 1700) in the Beaver Creek site (**Figures 7 & 8B**). This may be attributed to the slightly drier site conditions (Beaver Creek receives, on average, 4cm less precipitation annually than Jubilee Lake), and/or the prevalence of more decay-resistant species (e.g. western larch) that can better record and preserve fire evidence. A small peak in fire in ca. 1800 AD has been identified and reconstructed from charcoal particle density analysis from a small basin in the Elkhorn Range in the BME in NE Oregon (Long et al. 2019), with mean fire interval of 170 ±90 years during the co-occurring (1700-1950AD) period of this study.

There was a notable decrease in fire activity after 1900 at both the Jubilee Lake and Beaver Creek sites (**Figures 6-8**). The last widespread fire at Jubilee Lake was recorded in 1894, though there is evidence of some local and isolated events after this date. The last widespread fire at Beaver Creek was in 1802, though there were numerous recorded fires between 1800-1900 (**Figure 8B**). This aligns with the timing of an abrupt decrease in fire activity observed in other studies within the BME (e.g. Heyerdahl et al. 2001; Merschel et al. 2014; Johnston et al. 2016) and is likely explained by the effects of fire exclusion in the region (Hessburg et al. 1999). In the case of the steep terrain MMC forests in the northern BME, it is likely that successful suppression efforts at more accessible lower elevation forests have contributed to the prevention of fires from spreading into mid and higher elevation MMC forests. That said, fire has not been entirely excluded from the northern Blue Mountains, however, and a handful of fires have occurred in the 21st century in the Umatilla National Forest outside of our study area. According to wildfire perimeters recorded by the Monitoring Trends in Burn Severity Program (MTBS; Eidenshink et al. 2007), these recent fires appear to be more widespread (i.e. larger) than any fire events that we were able to reconstruct in this study. The lack of fire at both sites in this study area since the turn of the 20th century, which likely played a significant role in creating and sustaining patch heterogeneity historically, has probably contributed to a more homogeneous, densely forested landscape, as found in other studies in the region (e.g. Johnston 2017). Furthermore, increased fuel contagion across low-to-mid elevation landscapes (Hessburg et al. 2015), may have also contributed to increased fire spread into this MMC forest, as reported in high elevation forests elsewhere (e.g. Cansler et al. 2016).

Tree establishment peaks composed of primarily shade-tolerant species (e.g. grand fir and Engelmann spruce) were the dominant regeneration dynamic following fire events in the Jubilee Lake site (**Figures 10B & 12**). This was observed for fire events across all patches and all calculated severity levels. Grand fir was also present, though not as prevalent, in many post-fire cohorts at the Beaver Creek site (**Figure 11B**). The prolific presence of grand fir as an early seral species has been documented in post-fire regeneration studies within the Blues and elsewhere in the northwestern US (Cobb et al. 1993; Tepley et al. 2013; Kemp et al. 2016; Busby et al. 2020). Though Engelmann spruce is known to regenerate post-fire (Uchytil 1991; Sibold et al. 2007), it is less often mentioned in the literature than grand fir. For grand fir and Engelmann spruce to be present in a post-fire cohort, a few surviving trees must have been present locally as a seed source as these species are unable to re-sprout (Howard and Aleksoff 2000). The fine-scale patterning of both fire occurrence and severity we document is one mechanism that would help to explain this. In another study, presence of grand fir seedlings post-fire was found to be probable as far as 165m from a live seed tree (Kemp et al. 2016). Although grand fir is a prolific seed producer and disperser, the abundant grand fir regeneration that we documented initiating post-fire further indicates that patch size of historical high severity fire events was unlikely to be extensive, and provides further evidence of fine-scale patch heterogeneity at these sites, where seedbearing trees were available (refugia).

# 6. CONCLUSION

As a result of funding from Joint Fire Science Program (GRIN award number 19-1-01-49), we were able to process over 500 additional tree ring samples in the lab, and run more in-depth comparative and statistical analyses with the new and augmented dendroecological dataset. We have also contributed to the North American tree-ring fire-scar synthesis effort. As deliverables, we have presented this research on two occasions to the Northern Blues Forest Collaborative in eastern Oregon, as well as at the 8$^{th}$ International Fire Ecology and Management Congress in Tucson, Arizona in November 2019. Furthermore, we developed new insight into the historical fire regimes of moist mixed-conifer forests in the northern Blue Mountains.

The results of this study encourage us to appreciate variability along the fire regime spectrum across space and time, and the corresponding complexities in post-fire establishment and succession. This study highlights the challenges of reconstructing fire history in both these forest and fire regime types, and the importance of further research addressing fire history and forest change in this region.

## 6.1 KEY FINDINGS

1) Very high spatiotemporal variability in historical fire and establishment patterns was found over fine scales among forest stands. This illustrates the complexity of the historical forest dynamics in the study area, and suggests that forest patch-specific fire and tree age data are required to understand the nuances of historical fire and establishment patterns in these forests.
2) Fires were more frequent and more variable than previously thought in the study area, with median intervals ranging from 14-42 years, and 21-84 years in the two sites. This encourages us to question previous assumptions about the historical fire regime in these moist mixed-conifer forests.
3) Shade-tolerant species (such as grand fir and Engelmann spruce) were common in, and in some cases dominated, the post-fire establishment cohort. These findings question some assumptions, and instead open new perspectives, about relationship between fire traits and shade tolerance of the dominant tree species in these moist mixed-conifer forests and their historical mixed-severity fire regime.
4) Abrupt decrease in fire activity after 1900 at both sampled sites (with relatively abundant evidence of fire prior to this date) suggests that fire exclusion and active suppression by Euro-American settlers was largely effective in these forests. It is yet to be understood whether such effect was direct, or indirect (e.g. by suppressing fires at lower elevations that would have otherwise spread to these forest patches).

## 6.2 IMPLICATIONS TO MANAGEMENT AND FUTURE WORK

There is ongoing work to further refine the interpretations of historical fire regime characteristics in these, and additional subwatersheds in the BME. Two additional subwatersheds were sampled this past (2020) summer with the same approach, and will bring another 550-tree core and 41 fire scar samples to the dataset. Additional and more comprehensive analyses are in progress and include superposed epoch analysis to further investigate the climate-fire and climate-establishment relationships in the Jubilee Lake and Beaver Creek sites. These data will become part of a regional synthesis of patch-level fire history, structure, and composition to calibrate a fire severity model (see Hessburg et al. 2007) to infer whether or not current wildfires are creating forest conditions consistent with those created historically. Through field visits and presentations to forest managers and partners, this project has, and will continue to, contribute to discussion and understanding of forest restoration science, planning, and practice in moist forests.

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## APPENDIX A: CONTACT INFORMATION FOR KEY PROJECT PERSONNEL


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# APPENDIX B: LIST OF COMPLETED/PLANNED PRODUCTS

***Completed***

Conference and other Presentations

Platt, L. M., C. E. Naficy, K. B. Kemp, A. Holz. 2019. Disturbance Patterns and Stand Structure from Reconstructed Fire Severity and History: Lessons from Moist Mixed-Conifer Forests in the Blue Mountains of Northeast Oregon. *8th International Fire Ecology and Management Congress.* Tucson, Arizona.

Platt, L. M., K. B. Kemp, C. E. Naficy, A. Holz. 2020. Reconstructing historical fire regimes in moist mixed-conifer forests in the Northern Blues. *Northern Blues Forest Collaborative Meeting.* Enterprise, Oregon.

Thesis

Platt, L.M. 2020. Variability in historical fire patterns of a moist mixed-conifer forest in the northern Blue Mountains of Oregon. M.S. Thesis, Portland State University, Portland, Oregon.

Workshops/Field Tours

Northern Blues Forest Collaborative field tours, one in August 2019 and another in October 2020. At the sampled field sites, shared and discussed field observations, project progress, and management context of findings.

Field training opportunity. Summer 2020. A couple members from the USFS Regional Ecology group (Baker City, OR) joined us in the field to learn the details of dendroecological data collection as it pertains to this project.

***Planned***

Datasets

Platt, L. M., A. Holz, C. E. Naficy, K. B. Kemp. *In Prep.* Data from: Variability in historical fire patterns of moist mixed-conifer forests in the northern Blue Mountains of Oregon.

The above dataset will be made available in December 2022 following a two-year embargo period, or immediately following publication (whichever comes first).

Peer-Reviewed Publications

Platt, L. M., A. Holz, C. E. Naficy, K. B. Kemp. *In Prep.* Variability in historical fire patterns of moist mixed-conifer forests in the northern Blue Mountains of Oregon.

# APPENDIX C: METADATA

New field data collection, sample processing, and statistical analyses involved in this project led to the development of several new datasets. These datasets include the following:

1) Age structure data – data on the timing of tree establishment derived from tree-ring analyses of 1005 increment core samples of seven tree species from two sampled field sites. These data were collected from 67 age structure plots. Spreadsheet(s) will have metadata tabs appropriate to the type of data included.
2) Forest stand density and basal area data – data including the calculated per plot and per patch stem density and basal area (by species and by DBH size class). Spreadsheet(s) will have metadata tabs appropriate to the type of data included.
3) Fire history data – data on the timing of fire events derived from tree-ring analyses of 178 partial cross-section samples. Data is in FHX file format, prepared using the Fire History Analysis and Exploration System software.
4) Fire attribution per forest patch – calendar years of fire dates attributed to each forest patch in the study area. Spreadsheet(s) will have metadata tabs appropriate to the type of data included.

Details regarding the data collection and processing are described in the "Methods" section in this report. These data will be made publicly available either once the research has been published, or within two years of project completion (i.e., 12/31/2022), whichever comes first. When ready, the data will be archived in USFS Research Data Archive (https://www.fs.usda.gov/rds/archive/).